UNIVERSITI PUTRA MALAYSIA

COMPARISON OF THE EFFICIENCY BETWEEN FORCED-AIR WARMINGMATTRESS AND ELECTRIC HEATING PAD TO PREVENT PERIOPERATIVE HYPOTHERMIA IN DOGS AND CATS

LIM JIA HUI

COMPARISON OF THE EFFICIENCY BETWEEN FORCED-AIR WARMING MATTRESS AND ELECTRIC HEATING PAD TO PREVENT PERIOPERATIVE HYPOTHERMIA IN DOGS AND CATS

LIM JIA HUI

A project paper submitted to the
Faculty of Veterinary Medicine, Universiti Putra Malaysia (UPM)

In partial fulfillment of the requirement for the
DEGREE OF DOCTOR OF VETERINARY MEDICINE
Universiti Putra Malaysia
Serdang, Selangor Darul Ehsan

DECEMBER 2022

CERTIFICATION

It is hereby certified that we have read this project paper entitled "Comparison of The Efficiency Between Forced-air Warming Mattress and Electric Heating Pad to Prevent Perioperative Hypothermia in Dogs and Cats ", by Lim Jia Hui and in our opinion it is satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the course VPD4999 – Final Year Project.

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DEDICATION

This study is wholeheartedly dedicated to my respected supervisor and co-supervisors, for being my guidance and motivators.

To my family who become my spiritual and emotional support.

ACKNOWLEDGEMENT

First and foremost, I would like to acknowledge and express my gratitude towards my supervisor, Dr. Benedict Ong Huai Ern for his continuous guidance and advice which carried me through all the stages of my project.

Same goes to my co-supervisors, Dr. Michelle Fong Wai Cheng and Dr. Nurul Izzati Uda Zahli for their assistance and motivation.

I would like to thank my friends who always lend a helping hand and provide emotional support for me.

Last but not least, I would like to thank my family members who support and inspire me all the way.

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LIST OF ABBREVIATIONS

ASA	= American Society of Anesthesiologists
et al.	= *et al* (abbr. Latin) *et alii* (and others)
°C	= Degree Celsius
kg	= Kilogram
MAC	= Minimum alveolar concentration
mg	= Milligram
%	= Percentage
p	= Probability value
PVC	= Polyvinyl chloride
SEM	= Standard error of mean
T_{base}	= Rectal temperature before induction
T_{before}	= Rectal temperature under general anesthesia before warming
T_{after}	= Rectal temperature after warming at the end of the procedure

ABSTRAK

Abstrak kertas projek yang dikemukakan kepada Fakulti Perubatan Veterinar untuk memenuhi sebahagian daripada kursus VPD 4999 - Projek Tahun Akhir.

PERBANDINGAN ANTARA KEBERKESANAN TILAM PEMANASAN UDARA PAKSA DAN PAD PEMANASAN ELEKTRIK UNTUK MENGELAKKAN HIPOTERMIA PERIOPERATIF DALAM ANJING DAN KUCING

OLEH

LIM JIA HUI

2022

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Pengelakan hipotermia perioperatif menggunakan alat pemanasan intraoperatif yang cekap adalah penting bagi mengelakkan komplikasi yang memudaratkan seperti pemulihan yang berpanjangan, bradikardia, koagulopati, dan penurunan fungsi imun. Walau bagaimanapun, alat pemanasan yang berbeza didapati mempunyai kecekapan yang berbeza dalam meningkatkan atau mengekalkan suhu pesakit yang dibius. Oleh itu, kajian ini bertujuan untuk membandingkan kecekapan alat-alat pemanasan intraoperatif yang berbeza. Sebanyak 15 ekor anjing dan kucing yang dimasukkan ke hospital untuk pembedahan yang memerlukan bius selama 2 hingga 3.5 jam telah diambil sebagai subjek kajian. Setiap pesakit dibahagikan kepada salah satu daripada tiga kumpulan rawatan: kawalan negatif (tirai pembedahan sahaja) (n=5), tilam pemanasan udara paksa (n=5) atau pad pemanas elektrik (n=5). Suhu rektum sebelum induksi, sebelum pemanasan dan selepas pemanasan (di akhir prosedur) diukurkan. Peratusan purata perubahan suhu rektum bagi pesakit yang dibekalkan dengan tilam pemanasan udara paksa (+4.76 ± 1.52%) adalah jauh lebih tinggi (p=0.016) daripada kawalan negatif (-2.96 ± 1.05%) dan pad pemanas elektrik (-1.50 ± 1.34%). Hasil kajian menunjukkan bahawa tiada perbezaan yang signifikan (p=0.600) antara pad pemanas elektrik (-1.50 ± 1.34%) dan kawalan negatif (-2.96 ± 1.05%). Berbanding dengan pad pemanas elektrik yang berasaskan prinsip konduksi, tilam pemanasan paksa udara yang berasaskan prinsip perolakan adalah lebih berkesan dalam meningkatkan suhu badan pesakit yang dibius. Kesimpulannya, tilam pemanasan udara paksa adalah yang paling berkesan antara alat pemanasan yang terlibat dalam kajian kami.

Kata kunci : anjing, hipotermia perioperatif, kucing, tilam pemanasan udara paksa, pad pemanasan elektrik

ABSTRACT

An abstract of the project paper presented to Faculty of Veterinary Medicine in partial fulfillment of the course VPD 4999 - Final Year Project.

COMPARISON OF THE EFFICIENCY BETWEEN FORCED-AIR WARMING MATTRESS AND ELECTRIC HEATING PAD TO PREVENT PERIOPERATIVE HYPOTHERMIA IN DOGS AND CATS

By

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Preventing perioperative hypothermia using efficient intraoperative warming devices is crucial in avoiding detrimental complications such as prolonged recovery, bradycardia, coagulopathy, and reduced immune function. However, various types of warming devices are found to have different efficiency in increasing or maintaining the temperature of the anesthetized patients. Therefore, this study aimed to compare the efficiency of different intraoperative warming devices. Total 15 dogs and cats admitted for surgeries which required general anesthesia for 2 to 3.5 hours were recruited as the study subjects. Each patient was assigned to either one of the three treatment groups: negative control (drape only) (n=5), forced-air warming mattress (n=5) or electric heating pad (n=5). The rectal temperature before induction, before warming and after warming (at the end of the procedure) were measured. The average percentage of change in rectal temperature in patients supported with the forced-air warming mattress (+4.76 ± 1.52%) was significantly higher (p=0.016) than that of negative control (-2.96 ± 1.05%) and electric heating pad (-1.50 ± 1.34%). There was no significant difference (p=0.600) between the electric heating pad (-1.50 ± 1.34%) and negative control (-2.96 ± 1.05%). Compared to the conduction principle-based electric heating pad, convection principle-based forced-air warming mattress is more effective in increasing body temperature of the anesthetized patients. In conclusion, the forced-air warming mattress was the most effective among the warming devices involved in our study.

Keywords : cats, dogs, electric heating pad, forced-air warming mattress, perioperative hypothermia

1.0 INTRODUCTION

Hypothermia is defined as a state of decreased body temperature below the reference interval in homeothermic organisms. Perioperative hypothermia is a common complication in dogs and cats under general anesthesia (Aarnes *et al.*, 2017). In dogs and cats, the severity of hypothermia due to secondary causes such as general anesthesia was classified as mild (36.7°C to 37.7°C), moderate (35.5°C to 36.7°C), severe (33°C to 35.5°C), and critical (<33°C) (Oncken *et al.*, 2001). Retrospective studies have shown that more than 70% of cats and 32% of dogs had their temperature reduced to below 36.5°C during or after anesthesia (Redondo *et al.*, 2012). If there is no intervention introduced, the body temperature of the animals will continue to decline and complications may develop.

Hypothermia develops in three phases. During phase 1, the core temperature decreases rapidly. When general anesthesia lowers the temperature threshold, the body system of the animals will respond by increasing peripheral blood flow to remove the excessive heat. Moreover, some anesthetic drugs were found to induce peripheral vasodilation. This causes the heat to be redistributed from the core to the peripheral part of the body. During phase 2, the core temperature decreases in a slow linear form. This is because general anesthesia causes the metabolism of the body to decrease, resulting in reduced heat production (Mosing, 2016). During phase 3, the body temperature of the animals reaches a plateau due to the reactivation of thermoregulatory vasoconstriction which decreases the cutaneous heat loss. A thermal steady state is achieved because the heat production is equal to the heat loss (Mosing, 2016).

There are many causes that may result in perioperative hypothermia. Inhalant anesthetic-induced vasodilation caused by drugs like propofol and volatile inhalants is one of the common causes. When the blood flow in the periphery increases, it creates a larger surface area for the heat to be lost to the external environment. Meanwhile, the room temperature of the operation theater may affect the rate of heat loss from the patients through convection. Aside from that, the preparation of the surgical site using a cold solution, administration of cold inhaled gas via anesthetic machine, and intravenous fluid may also contribute to perioperative hypothermia (Taguchi and Kurz, 2005).

Perioperative hypothermia may lead to various detrimental effects. For example, prolonged recovery from general anesthesia, increased risk of infection, coagulopathy, and bradycardia (Mosing, 2016). In order to prevent the perioperative complications and consequences caused by hypothermia, the usage of intraoperative warming devices should be considered. Warming methods are generally classified into two major groups including passive and active forms (Armstrong, 2005).

However, it was stated that passive insulation alone is rarely sufficient to maintain normothermia in patients undergoing long procedures and is not as effective as the active warming methods (Clark-Price, 2015). Active warming is usually required to compensate for the heat loss in patients under general anesthesia. Active warming devices work by actively transferring heat to anesthetized patients. Therefore, they were found to be able to prevent perioperative hypothermia and contribute to better postoperative outcomes if they are properly used (Franklin, 2008). Studies have shown that the usage of both warm air heating devices and electric heat mats can treat anesthesia-induced hypothermia effectively (Kibanda and Gurney, 2012). As the working principles of these warming devices differ, their efficiency in patient warming may differ.

In Malaysia, based on the author's personal observation, intraoperative patient warming is not commonly applied in dogs and cats undergoing general anesthesia. Moreover, the availability of the marketed intraoperative active warming devices in Malaysia and the relevant study of their efficacy are limited. In this study, we compare two types of warming devices which are forced-air warming mattresses and electric heating pad used in University Veterinary Hospital (UVH), University Putra Malaysia (UPM). This study will determine the efficiency of these warming devices and suggest a more practical intraoperative warming regime in maintaining normothermia in the anesthetized dogs and cats.

2.0 LITERATURE REVIEW

2.1 PASSIVE WARMING

Passive warming works by preventing further heat loss from the body of the patient (Armstrong *et al*. 2005). However, it does not actively increase the temperature of the surroundings of the patient. Passive warming utilizes the concept of insulation. The insulators trap the heat of the patient by covering the skin of the patient. It was stated that one layer of passive insulator reduces 30% while three layers of passive insulator reduce 50% of heat loss from the skin of the patient to the external environment through radiation, conduction, and convection while the animals generate heat on their own (Mosing, 2016).

2.1.1 SURGICAL DRAPE

Patients undergoing surgery are usually covered with surgical drapes. Aside from preventing contact with the unprepared areas and maintaining sterility of the surgical site, the surgical drape also acts as an insulator that helps to trap the heat, avoiding it from being lost into the air flowing over the skin. Convective heat loss is still recognized as the second most important source of heat loss. Thus, to prevent perioperative hypothermia effectively, draping should be done in combination with other warming methods. The previous study has shown that the human patients undergoing laparoscopic surgery who were covered with surgical drapes only without any other active warming devices had their body temperature decreased by 0.8 (± 0.3)°C at the end of the surgery (Campos *et al*., 2005).

2.1.2 BLANKET

The insulation provided by the blanket is mainly due to the air between the blanket and the patient but not the blanket itself. The air acts as an insulator to trap and retain the heat next to the body, preventing 30% of the heat loss (Mosing, 2016). Since a blanket does not provide an active heat source to the patient, its warming function depends on the surface area of the body covered by itself. The cutaneous heat loss and the efficacy of the blanket are directly proportional to the size of the covered surface area of the patient's body (Sessler, 2001). Aside from that, study has revealed that increasing the number of layers of the insulator only causes slight reduction in the heat loss. There was only a small reduction (18 ± 6%) observed in the temperature of the skin in the patients covered with three layers of blanket compared to the patient covered with one layer of blanket (Sessler and Schroeder, 1993).

2.1.3 REFLECTIVE BLANKET

Reflective blankets such as metallic blankets made of aluminium are designed to reflect heat, reducing heat loss via radiation (Tunsmeyer *et al*., 2009). Meanwhile, metallic blankets also reduce convective and conductive heat loss effectively when it is wrapped or covered on the body of the patient (Mosing, 2016). Study has shown that the esophageal temperature of the dogs undergoing celiotomy supplemented with supplemental heat (a reflective blanket covered the cervical and thoracic regions, reflective blankets covered three limbs and wool socks covered from the digits to the axillary or inguinal region) was significantly higher than that of the patients who were only provided with routine heat supports (O'Neil and Linklater, 2022). Another study also demonstrated the ability of the reflective blanket to significantly increase the body temperature in dogs under general anesthesia (Tunsmeyer *et al*., 2009).

2.1.4 BUBBLE WRAP

Bubble wrap is a plastic sheet with regularly spaced protruding pockets filled with air. Unlike liquid and solid, air has lower heat conductivity. Therefore, it helps to trap the body heat and prevent it from escaping to the surroundings. At the same time, it also helps to preserve the body heat of the patient by minimizing the conductive and convective heat loss. It is a low cost, easily available and modified passive warming tool. A survey conducted among the pre-hospital units such as human ambulance, search and rescue services has shown that bubble wrap was one of the most commonly used insulators in preventing and treating hypothermia in human patients before they received their treatment in hospital (Karlsen, 2013). A study has demonstrated that the mean body temperature of the cats undergoing ovariohysterectomy with their limbs and thorax wrapped with two layers of bubble wrap and an absorbent pad was significantly higher than the unwrapped group at the end of isoflurane administration. Besides, the wrapped group also recovered and regained the ability to stand up again significantly faster than the unwrapped group (Sakata, 2020).

2.2 ACTIVE WARMING

Active warming increases the temperature of the surface or the air over the surface of the patient's body, reducing the temperature gradient. Compared to the passive warming which only works well in mild hypothermic cases, active warming works for hypothermia of different severity (Quandt, 2018). Instead of warming the trunk, it was recommended to warm the feet and legs as it helps to maintain normothermia more effectively. In a previous study, dogs supported with the warm circulating mattress around their feet and legs had the highest minimum mean temperature compared to the other dogs supported with the active warming device around their trunk. The core temperature of the peripheral warming dogs was maintained significantly higher than the trunk warming dogs throughout the 2.5-hour orthopedic or dental procedures (Cabell, 1997).

2.2.1 ELECTRIC HEATING PAD

Electric heating pad warms the body parts of the patient which are in direct contact with its heating surface. It was stated that an electric heating pad alone may be able to maintain core temperature for short and non-invasive procedures (Tan *et al.*, 2004). However, it may not be able to maintain normothermia in patients undergoing prolonged anesthesia and surgery. It has been stated that an electric heating pad supports the patient better if it is used in combination with other warming methods such as hot water bottles and warmed intravenous fluid (Tan *et al*., 2004). Some conventional electric heating pads without temperature sensors which are known as thermal 'cells' may continue to heat the focal points until the preset temperature is exceeded, resulting in thermal injury in high-pressure regions, especially the bony prominence areas (Tan *et al*., 2004).

2.2.2 CIRCULATING WATER BLANKET

Circulating water blanket has an electric heater to warm the water and the warm water will flow into the plastic blanket, delivering heat to the patient (Franklin, 2008). Previous study has demonstrated that circulating warm water pad has an initial significantly higher temperature than the dogs placed on a steel table without any warming device at the 35th minutes of anesthesia. In other words, a circulating warm water pad has the advantage over placing patients on the table without any warming devices for procedures longer than 35 minutes (Clark-Price *et al*., 2013). However, the efficacy of the circulating water blankets is limited if they are placed on the dorsum of the animals as their dorsum only provides a small surface area if compared to the ventral surface. Besides, the capillaries will be compressed by the body weight of the patients and the blood flow which delivers the heat will be restricted if the blanket is placed under the patient (Sessler, 2001).

2.2.3 FORCED-AIR WARMING SYSTEM

Forced-air warming system usually consists of a heating unit that warms the air at different temperature settings and a blower that functions to force the air into the hose and inflate the blanket. The warm air then exits through the perforations on the blanket to reach and warm the patient through convection. Forced-air warming devices are usually versatile in that they can be placed on or beneath the patients. Aside from that, forced-air warming devices are available in various sizes and shapes which are able to fit different patients for different types of procedures (Franklin, 2008). There are different forms of forced-air warming devices such as Bair Hugger® and Cocoon® which come from different manufacturers. Study has shown that the forced-air warming system results in significantly higher temperature in the dogs compared to the dogs placed on the steel table without any warming devices at 20th minutes and the dogs supported with a cotton towel at 30 minutes (Clark-Price *et al.*, 2013). Therefore, the forced-air warming mattress has an advantage over the cotton towel for procedures longer than 30 minutes.

2.3 IMPORTANCE OF WARMING

Perioperative hypothermia should not be overlooked as it may result in various devastating physiological complications and cause undesired outcomes in the affected patients. Appropriate warming with proper monitoring is often required to maintain normothermia in patients under general anesthesia.

Perioperative hypothermia decreases the rate of drug metabolism (Tortorici *et al.*, 2007), resulting in prolonged recovery in the anesthetized patients. Study has shown that blood propofol concentration was 28% significantly higher at body temperature of 34°C than at 37°C (Leslie, 1995). It was found to be associated with the hepatic blood flow as the clearance of propofol depends on the hepatic blood flow but the hepatic blood volume was shown to be significantly reduced by hypothermia (Leslie, 1995). Another study also showed that there was significant delay of recovery from anesthesia in mildly hypothermic human patients with abdominal surgery (Lenhardt *et al*., 1997). Hypothermia also increases the anesthetic potency by reducing minimum alveolar concentration (MAC) of anesthetic inhalants. Previous study has shown that there was rectilinear reduction in MAC in tracheotomized rats which were anesthetized with halothane and isoflurane when the temperature of the rats was reduced (Vitez *et al*., 1974). Another study also showed that the dog and cat patients from the induction and operation rooms at 24 °C were extubated earlier (5 minutes) than those from colder rooms (7 minutes) (Rodriguez-Diaz *et al*., 2020).

It was found that hypothermia may affect the function of the platelets. Study has shown that platelet aggregation significantly decreased in dogs with prolonged hypothermia. Hypothermia does not affect the level of the clotting factors. However, it slows down the enzymatic reactions of intrinsic and extrinsic cascades of blood coagulation (Ao *et al*., 2001).

Apart from that, hypothermia impairs immune function and increases risk of infection. Hypothermia causes vasoconstriction which leads to poor perfusion to the periphery and tissue hypoxia at the surgical site (Sessler, 2001). It also decreases oxidative killing by neutrophils and reduces phagocytosis. In human study, the incidence of surgical infection in hypothermia group is 19% which is higher than 6% recorded by normothermia group (Kurz, 1996).

Furthermore, moderate hypothermia may cause reduced spontaneous depolarization of the cardiac pacemaker cells, resulting in bradycardia which is unresponsive to the administration of atropine (Mallet, 2002).

The objective of this study is

1. To determine the effect of different intraoperative warming devices on the changes in rectal temperature in patients under general anesthesia.

3.0 MATERIALS AND METHOD

3.1 RESEARCH DESIGN

A prospective study was conducted to compare the efficiency between forced-air warming mattress and electric heating pad after obtaining approval from Institutional Animal Care and Use Committees (IACUC).

3.2 STUDY POPULATION

A total of 15 dog and cat patients admitted into University Veterinary Hospital, Universiti Putra Malaysia for surgeries in 2022 with the criteria of requiring general anesthesia for 2 to 3.5 hours and being classified as American Society of Anesthesiologists (ASA) class I to III with normothermia before general anesthesia were recruited into this study as our study subjects. A clear explanation was made to the owners and consent was obtained from them before their pets were included in the study.

3.3 MATERIALS AND METHODS

3.3.1 INDUCTION AND MAINTENANCE OF GENERAL ANESTHESIA

The dogs and cats were kept in individual cages and intravenous catheter placement was done on their cephalic vein before the procedures. Pre-medications were given based on the needs of the individual patients.

4-10 mg/kg of propofol was administered intravenously to induce general anesthesia and the patients were intubated using endotracheal tubes. Preoperative skin preparation was done soon after the patients were induced. The surgical site was shaved using a clipper and scrubbed with diluted chlorhexidine. 70% alcohol and iodine were applied on the cleaned surgical site. The patients were then transferred to the operation theater and maintained using isoflurane gas.

3.3.2 INTRAOPERATIVE WARMING

The patient was placed on the surgery table with either a forced-air warming mattress (WarmAir® Model 135, United States of America) or an electric heating pad (Far Infrared Heating Warming Therapeutic Pad, MHP-E1220, China). The electric heating pad was placed under a layer of the towel while the forced-air warming mattress was placed underneath the patient directly and connected to a reusable cushion (LONGSHORE® WARM AIR cushion, China). The temperature of the forced-air warming mattress was set at 43℃ while the temperature of the electric heating pad was set at 40℃. The patients in the negative control group were not provided with any intraoperative active warming devices. However, the patients in all treatment groups were still covered with the surgical drape including the negative control group before the surgery started.

3.3.3 MEASUREMENT OF RECTAL TEMPERATURE

There were three measurements of rectal temperature taken throughout the procedures using a digital thermometer (OMRON MC-343F, Japan). The first measurement taken was the rectal temperature before induction, T_{base}. Next, the rectal temperature under general anesthesia before warming, T_{before} was measured. T_{before} was taken after the induction and surgical preparation before the patients were transferred to the operation theater. The last measurement taken was the rectal temperature after warming at the end of the surgery, T_{after}. It was measured when the surgery ended and the isoflurane gas was turned off. The data was then recorded in the data spreadsheet (Microsoft® Excel® 2019, United States).

3.3.4 CALCULATION OF PERCENTAGE OF CHANGE IN RECTAL TEMPERATURE

The percentage of change in rectal temperature was calculated using the formula:

$$\textit{Percentage of change in rectal temperature} = \frac{T_{after} - T_{before}}{T_{before}}$$

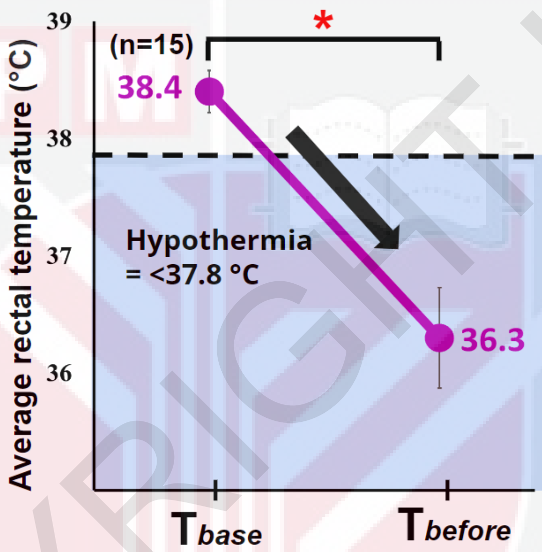
3.4 STATISTICAL ANALYSIS

The data was inserted into and analyzed using IBM SPSS Statistical Software 23.0 (IBM SPSS® Statistics, United States of America). Normality test was done on T_{base}, T_{before} and T_{after}. Their normality was determined using Shapiro Wilk's test. The mean T_{base} was compared with mean T_{before} for all fifteen samples using paired t-test to determine whether there is any significant difference between them. Meanwhile, the mean T_{before} was compared with mean T_{after} for each treatment group separately using paired t-test. The average percentage of change in rectal temperature between each of the treatment groups was compared using Mann-Whitney U test. A p-value of less than 0.05 was considered statistically significant.

4.0 RESULTS

4.1 REDUCTION IN RECTAL TEMPERATURE AFTER INDUCTION OF GENERAL ANESTHESIA

Figure 1: The average rectal temperature of the patient before induction and before warming



* = significant difference

Before the induction of general anesthesia, the patients had the average rectal temperature ± Standard Error of Mean (SEM) before induction, T_{base} of 38.4 ± 0.18 °C. However, after the induction of general anesthesia, their average rectal temperature started to decline and achieved the average rectal temperature ± SEM under general anesthesia before warming, T_{before} of 36.3 ± 0.43 °C.

Table 1: Mean and Standard Error of Mean of Rectal Temperature Before Induction and Before Warming (°C).

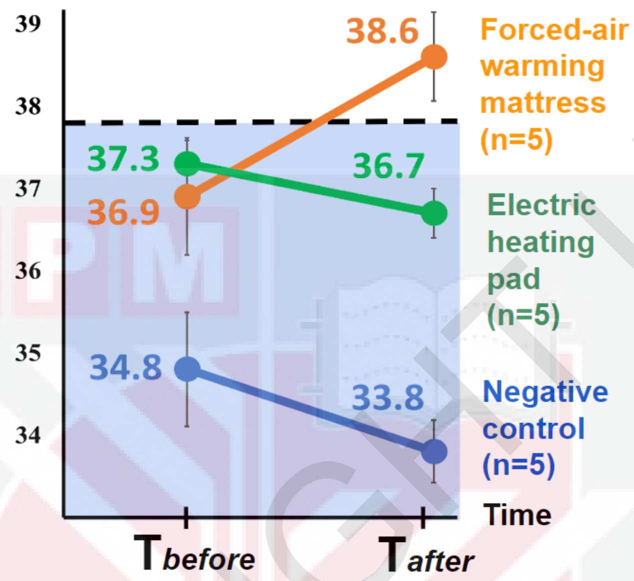
	T_{base} (°C)		T_{before} (°C)	
	Mean	**SEM**	**Mean**	**SEM**
All Samples	38.4 [a]	0.18	36.3 [a]	0.43

[a] = Significant difference ($p < 0.05$) between rectal temperature before induction and before warming

The rectal temperature before induction of all samples had a mean ± SEM of 38.4 ± 0.18 °C while rectal temperature before warming of all samples had a mean ± SEM of 36.3 ± 0.43 °C (Table 1). Based on the paired sample t-test, the rectal temperature before induction was significantly higher than the rectal temperature before warming of all samples ($p = 0.0001$) at 95% confidence level.

4.2 CHANGE IN RECTAL TEMPERATURE AFTER WARMING

Figure 2: The average rectal temperature of the patient before warming and after warming



After the patients were transferred to the operation theater and the warming devices were used to warm the patients, the average rectal temperature of each treatment group underwent different forms of changes. For the negative control group, their average rectal temperature decreased from 34.8°C (T_{before}) to 33.8°C (T_{after}). For the forced-air warming mattress group, their average rectal temperature increased from 36.9°C (T_{before}) to 38.6°C (T_{after}). For the electric heating pad group, their average rectal temperature decreased from 37.3°C (T_{before}) to 36.7°C (T_{after}).

Table 2: Mean and Standard Error of Mean of Rectal Temperature Before and After Warming

	T_{before} (°C)		T_{after} (°C)	
	Mean	**SEM**	**Mean**	**SEM**
Negative control	34.8	0.69	33.8	0.38
Forced-air Warming Mattress	36.9 [b]	0.71	38.6 [b]	0.54
Electric Heating Pad	37.3	0.28	36.7	0.30

b = Significant difference ($p < 0.05$) between rectal temperature before warming and after warming in forced-air warming mattress

The rectal temperature before warming (T_{before}) of the negative control group had a mean ± SEM of 34.8 ± 0.69 °C while the rectal temperature after warming (T_{after}) had a mean ± SEM of 33.8 ± 0.38 °C (Table 2). Based on the paired sample t-test, there was no significant difference in rectal temperature before warming and after warming of the negative control group ($p = 0.057$) at 95% confidence level.

The rectal temperature before warming (T_{before}) of the forced-air warming mattress group had a mean ± SEM of 36.9 ± 0.71 °C while the rectal temperature after warming (T_{after}) had a mean ± SEM of 38.6 ± 0.54 °C (Table 2). Based on the paired sample t-test, for the patients supported with the forced-air warming mattress, their rectal temperature after warming was significantly higher than their rectal temperature before warming (p = 0.036) at 95% confidence level.

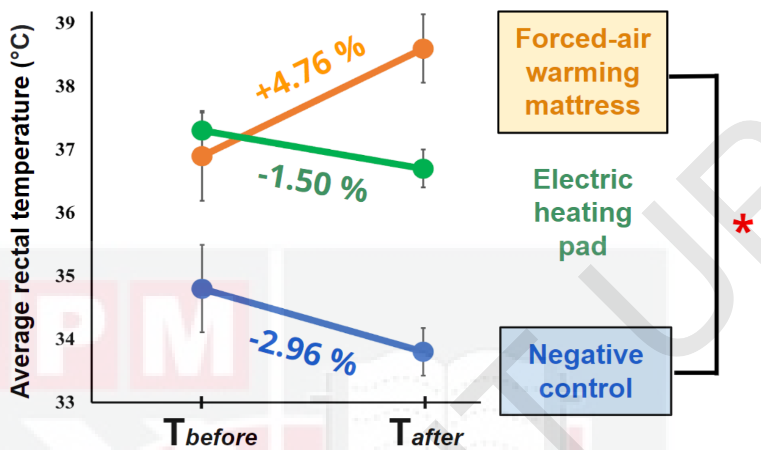
The rectal temperature before warming (T_{before}) of the electric heating pad group had a mean ± SEM of 37.3 ± 0.28 °C while the rectal temperature after warming (T_{after}) had a mean ± SEM of 36.7 ± 0.30 °C (Table 2). Based on the paired sample t-test, there was no significant difference in rectal temperature before warming and after warming of the electric heating pad (p = 0.312) at 95% confidence level.

Table 3: Mean and Standard Error of Mean of Percentage of Change in Rectal Temperature

	Percentage of Change in Rectal Temperature (%)	
	Mean	**SEM**
Negative control	-2.96	1.05
Forced-air Warming Mattress	+ 4.76	1.52
Electric Heating Pad	-1.50	1.34

The percentage of change in rectal temperature of the negative control group had a mean ± SEM of -2.96 ± 1.05%. The percentage of change in rectal temperature of the forced-air warming mattress had a mean ± SEM of +4.76 ± 1.52 % while the percentage of change in rectal temperature of the electric heating pad group had a mean ± SEM of -1.50 ± 1.34 % (Table 3).

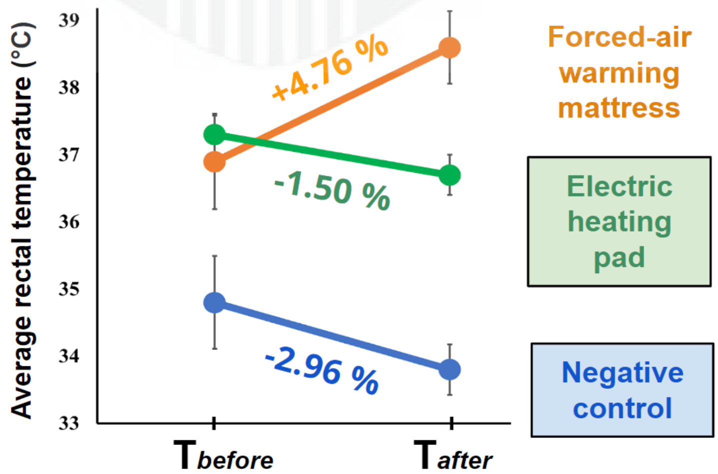
Figure 3: Comparison of percentage of change in rectal temperature between the negative control group and the forced-air warming mattress group



* = significant difference

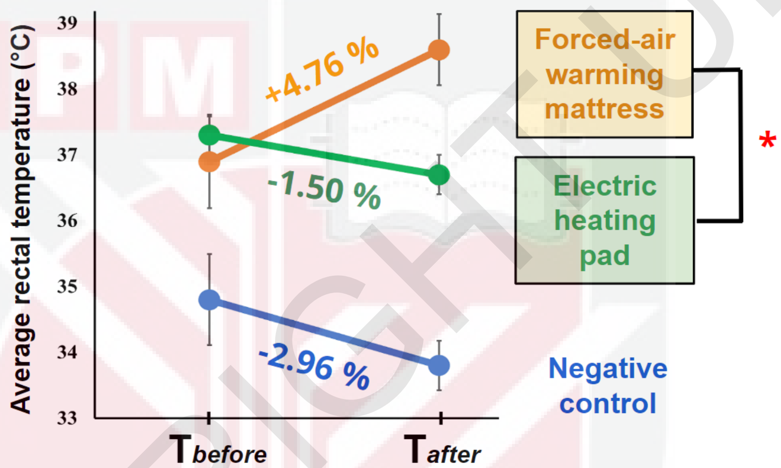
Based on the Mann-Whitney U test, the percentage of change in rectal temperature of the forced-air warming mattress group was significantly higher than the negative control group ($p = 0.016$) at 95% confidence level.

Figure 4: Comparison of percentage of change in rectal temperature between the negative control group and the electric heating pad group



There was no significant difference in percentage of change in rectal temperature between the negative control group and the electric heating pad group (p = 0.600) at 95% confidence level.

Figure 5: Comparison of percentage of change in rectal temperature between the forced-air warming mattress and electric heating pad group



* = significant difference

The percentage of change in rectal temperature in the forced-air warming mattress group was significantly higher than the negative control group (p = 0.016) at 95% confidence level.

5.0 DISCUSSION

5.1 REDUCTION OF RECTAL TEMPERATURE AFTER INDUCTION OF GENERAL ANESTHESIA

After induction of the general anesthesia, the average rectal temperature of the patients decreased. In other words, hypothermia developed after induction. It was most likely due to vasodilation induced by anesthetic agents such as propofol and isoflurane inhalant used in this study. Since the peripheral vascular tone was affected, peripheral vasodilation occurred and the core heat was mixed with peripheral heat. Thus, heat was redistributed from the central to the peripheral parts of the patient and lost to the surroundings (Mosing, 2016). Besides, propofol lowered the temperature threshold for shivering and peripheral vasoconstriction, reducing heat generation and preservation (Matsukawa *et al*., 1995). Additionally, the volatile alcohol-based solution used for surgical preparation caused evaporative loss of heat from the body of the patient. Meanwhile, animals under general anesthesia also lost their ability to move voluntarily, thus muscle activity cannot be stimulated to generate heat (Davies, 2012).

5.2 CHANGE IN RECTAL TEMPERATURE AFTER WARMING

The negative control group showed the most drastic reduction in their rectal temperature among the three treatment groups. To put it another way, the passive warming method alone which was the surgical drape alone was the least effective if compared to the forced-air warming mattress and electric heating pad. The surgical drape did not provide an external heat supply but acted as an insulator which trapped the heat of the patient by covering the skin surface, preventing part of heat loss from the patient (Armstrong *et al*., 2005). It was found that one layer of surgical drape only reduces 30% of heat loss from the skin so there was still some heat lost to the surroundings (Mosing, 2016). Radiation of infrared waves accounted for the most heat loss and it was not significantly reduced by common warming methods (Grimm, 2015). Besides, part of heat was lost from the blood flowing under the uncovered skin to the air molecules moving over the skin surface via convection. This is because the passive insulation covering the patient only helps to reduce the 30% effect of convection by trapping the airflow around the patient (Grimm, 2015). Apart from that, some heat was lost to the surroundings from the open body cavities, especially in the patients which underwent laparotomy via evaporation (Mosing, 2016). Moreover, the surgical drape did not actively increase the temperature of the skin surface and the surroundings of the patient. Therefore, the rectal temperature of the anesthetized patients still decreased even though they were covered with the surgical drape. Previous study supports our findings as it shows that human patients supported with passive warming devices alone under general anesthesia had their body temperature significantly decreased from 36.8 (± 0.6) °C to 35.1°C (± 0.5) °C (Lindwall *et al.*, 1998).

After being provided with the supplementation of the forced-air warming system (WarmAir® Model 135, United States of America), the rectal temperature of the patient significantly increased and the percentage of change in rectal temperature was significantly higher than both of the negative control and electric heating pad groups. It revealed that the efficiency of the forced-air warming mattress was superior to the other devices involved in this study. Forced-air warming mattresses provided effective active surface warming by employing air convection. The air from the surroundings was drawn into the intake filter and was heated by the heat generator. The heated air was forced by the blower through the hose into the reusable mattress (Ackermann *et al*., 2018). The warm air then permeated the slits on the mattress to form a shell of warm air around the patient. Meanwhile, the parts of the mattress which were in direct contact with the body of the patient also conducted the heat to the body of the patient lying on it. The mattress filled with warm air fitted all patients with different body shapes and sizes, thus the heat was conducted uniformly to the body of the patient. The convective and conductive warming provided by the forced-air warming mattress reduced the gradient between the patient and environment (Clark-Price *et al*., 2013), reducing the rate of heat loss from the patient. Previous study shows similar findings that human patients supported with a forced-air warming mattress under general anesthesia had their body temperature increased from 36.9 (± 1.6) °C to 38.6°C (± 1.2) °C (Lindwall *et al*., 1998). Additionally, the forced-air warming system is also equipped with the thermistor at the hose outlet and a safety thermostat which allows the unit to cool down if overheating condition is detected.

After being provided with the electric heating pad (Far Infrared Heating Warming Therapeutic Pad, MHP-E1220, China), the rectal temperature of the patient decreased. There was a significant difference in the percentage of change in rectal temperature between the electric heating pad and the forced-air warming mattress group but not between the electric heating pad and negative control group. Our findings indicated that the warming provided by the electric heating pad was not as superior as that of the forced-air warming mattress and its efficiency in increasing the rectal temperature of the patient was similar to that of negative control. The electric heating pad used in our study is a green polyvinyl chloride (PVC) mat with a carbon fiber heating element implanted inside. The carbon fiber is able to produce 30% more heat if compared to the metal wire. Therefore, when the power was switched on, the temperature was elevated rapidly. Unlike the forced-air warming mattress, the flat surface of the electric heating pad did not fit the shape of the body of the patient well. Since the local pressure points like the bony protuberances which were in direct contact with the pad, the heat was mostly focused on those points only. Furthermore, heat is dissipated by blood flow so local heating always depends on the tissue perfusion (Zhang, 2017). When the patient was lying on the electric heating pad, the blood vessels in the pressure points were compressed and those areas became ischemic. Since the blood perfusion and circulation in the pressure points was poor, the heat was not well distributed to the core of the body of the patient, resulting in poor warming. Our study shows similar findings as the previous study in which the rectal temperature of the dog patients supported with electric heating pad decreased for 3.1 (±1.1) °C. (Tan *et al*., 2004).

The electric heating pad should be used with extra caution as it poses a risk of causing thermal injury. The heat supplied by the electric heating pad accumulates in the hypoperfused tissues at the pressure point area, resulting in thermal injury. Some electric heating pads without temperature sensors may continue to heat the patient until the preset temperature is exceeded (Tan *et al*., 2004). In the meantime, the anesthetized patients lost their innate protective response which enabled them to move away from the heat source and change their body position to avoid the heat source from burning one area of their body (Grimm, 2015). These factors cause the patients supported with electric heating pad more prone to thermal injury.

However, the risk of thermal injury in patients supported with the forced-air warming mattress is lower. In human patients using the force-air warming system, there were only a few thermal injury cases reported among 15 to 25 million uses per year (Bräuer and Quintel, 2009). This is because the forced-air warming mattress circulates a large volume of warm air with each of the air molecules carrying a smaller amount of heat energy (Grimm, 2015). A thermal injury case has been reported in a 13-year-old female poodle with

gallbladder rupture and hypoperfusion which was admitted for surgery and supported with a forced-air warming system. However, the burn was attributed to the direct hosing without blanket attachment which caused the heat to focus on a single spot only, as well as the hypoperfusion which hindered the heat to be dissipated from that single area (Lee *et al*., 2020).

6.0 CONCLUSION

In conclusion, the forced-air warming mattress is the most effective warming device which increases the rectal temperature of dog and cat patients under general anesthesia among the 3 treatment groups in our study. Its usage is recommended in surgery lasting for 2 to 3.5 hours in order to maintain normothermia and combat perioperative hypothermia in anesthetized patients, preventing various devastating physiological effects caused by hypothermia.

7.0 RECOMMENDATIONS

This study has some limitations. Firstly, the room temperature of the operation theaters was not controlled and monitored. Thus, there was a possibility one operation theater's room temperature might be slightly different from another operation theater. The lower the room temperature, the higher the temperature gradient between the patient and the surroundings. This resulted in a higher rate of heat loss from the body of the patient, leading to lower rectal temperature of the patient at the end of the surgery. Therefore, it is recommended to set a fixed ambient temperature of the surgical preparation and operation theater. Previous study has shown that hypothermia was reported in 35.6% of the dog and cat patients in the induction room at 21.2°C and operating room at 18.6°C. Solely increasing the room temperature to 24°C without modifying the warming protocol has successfully reduced the hypothermia incidence in dog and cat patients to 13% (Rodriguez-Diaz *et al*., 2020).

The duration of general anesthesia is one of the limitations of our study. The study subjects involved in our study have duration of general anesthesia ranging from 2 to 3.5 hours. The patients undergoing longer duration of general anesthesia had more heat loss and lower rectal temperature of the patient at the end of the surgery. Thus, it is recommended to minimize the duration between induction and surgery, as well as the entire duration of general anesthesia, especially after the surgical site of the patient has been clipped and scrubbed when there is more heat lost via evaporation (Rodriguez-Diaz *et al*., 2020).

Apart from that, our study subjects are not categorized based on the types of the surgery. It is recommended that the subjects should be divided into laparotomy and non-laparotomy groups or only either one of the groups is studied. This is because laparotomy is an invasive procedure which opens the abdominal cavity and exposes the internal structures. It allows more heat to be lost via vaporized liquid from the open body cavity (Grimm, 2015).

8.0 REFERENCES

Aarnes, T.K., Bednarski, R.M., Lerche, P. and Hubbell, J. E. (2017). Effect of pre-warming on perioperative hypothermia and anesthetic recovery in small breed dogs undergoing ovariohysterectomy. Can. Vet. J. 58(2): 175–179.

Ackermann, W., Fan, Q., Parekh, A. J., Stoicea, N., Ryan, J., & Bergese, S. D. (2018). Forced-air warming and resistive heating devices. Updated perspectives on safety and surgical site infections. Front. Surg. 5: 64.

Ao, H., Moon, J.K., Tashiro, M. and Terasaki, H. (2001). Delayed platelet dysfunction in prolonged induced canine hypothermia. Resuscitation. 51(1): 83–90.

Armstrong, S.R., Roberts, B.K. and Aronsohn, M. (2005). Perioperative hypothermia. J. Vet. Emerg. Crit. Care. 15(1): 32–37.

Bräuer, A. and Quintel, M. (2009). Forced-air warming: Technology, physical background and practical aspects. Curr. Opin. Anaesthesiol. 22(6): 769-774.

Cabell, L.W., Perkowski, S.Z., Gregor, T. and Smith, G.K. (1997). The effects of active peripheral skin warming on perioperative hypothermia in dogs. Vet. Surg. 26(2):79-85.

Campos, J.M., Piñol, S., Remartínez, F. and Casas, J.I. (2005). Prevention of intraoperative hypothermia during laparoscopic surgery of long duration: A-147. Eur. J. Anaesthesiol. 22: 40-41.

Clark-Price, S.C., Dossin, O., Jones, K.R., Otto, A.N. and Weng, H.Y. (2013). Comparison of three different methods to prevent heat loss in healthy dogs undergoing 90 minutes of general anesthesia. Vet. Anaesth. Analg. 40(3): 280–284.

Clark-Price, S. (2015). Inadvertent perianesthetic hypothermia in small animal patients. Vet. Clin. North Am. Small Anim. Pract. 45(5): 983–994.

Davies, T. (2012). How to prevent perioperative hypothermia in the dog and cat: Causes and consequences. Vet. Nurs. J. 3(1): 42–47.

Epstein, A., Avni, G., Laset, G and Aroch, I. (2013). Prevention of perioperative hypothermia in anesthetized dogs using a novel computerized body temperature regulation system. Isr. J. Vet. Med. 68: 19-27.

Franklin, M.A. (2008). Comparison of three intraoperative warming devices, Master's thesis, Oklahoma.

Grimm, K.A. (2015). Perioperative Thermoregulation and Heat Balance. In: Veterinary Anesthesia and Analgesia. Grimm, K.A., Lamont, L.A., Tranquilli, W.J., Greene, S.A. and Robertson, S.A. (Eds.) 5th ed., John Wiley & Sons, Inc, United States of America. pp. 374-376.

Karlsen, A.M., Thomassen, O., Vikenes, B.H. and Brattebø, G. (2013). Equipment to prevent, diagnose, and treat hypothermia: a survey of Norwegian pre-hospital services. Scandw. J. Trauma. Resusc. Emerg. Med. 21: 63.

Kibanda, J.O. and Gurney, M. (2012). Comparison of two methods for the management of intraoperative hypothermia in dogs. Vet. Rec. 170(15): 392.

Kurz, A., Sessler, D.I. and Lenhardt, R. (1996). Perioperative normothermia to reduce the incidence of surgical-wound infection and shorten hospitalization. N. Engl. J. Med. 334(19): 1209-1216.

Lee, S., Lee, A., Lee, M. and Kim, W. (2020). Thermal Burn Injury from a Forced-Air Warming Device in an Anesthetized Dog with Peripheral Hypoperfusion. J. Vet. Clin. 37: 331-335.

Lenhardt, R., Marker, E., Goll, V., Tschernich, H., Kurz, A., Sessler, D.I., Narzt, E. and Lackner, F. (1997). Mild intraoperative hypothermia prolongs postanesthetic recovery. Anesthesiology. 87(6): 1318-23.

Leslie, K., Sessler, D.I., Bjorksten, A.R. and Moayeri, A. (1995). Mild hypothermia alters propofol pharmacokinetics and increases the duration of action of atracurium. Anesth. Analg. 80:1007-14.

Lindwall, R., Svensson, H., Söderström, S. and Blomqvist, H. (1998). Forced air warming and intraoperative hypothermia. Eur. J. Surg. 164(1): 13-16.

Mallet, M.L. (2002). Pathophysiology of accidental hypothermia. QJM: An International Journal of Medicine. 95(12): 775–785.

Matsukawa, T., Kurz, A., Sessler, D.I., Bjorksten, A.R., Merrifield, B. and Cheng, C. (1995). Propofol linearly reduces the vasoconstriction and shivering thresholds. Anesthesiology. 82: 1169-1180.

Mosing, M. (2016). General principles of perioperative care. In: BSAVA Manual of Canine and Feline Anaesthesia and Analgesia. Duke-Novakovski, T., Vries, M.d. and Seymour, C. (Eds) 3rd ed., British Small Animal Veterinary Association. Pp.17-22.

Oncken, A.K., Kirby, R. and Rudloff, E. (2001). Hypothermia in Critically Ill Dogs and Cats. Compend Contin Educ Vet. 23: 506-520.

O' Neil, B.A. and Linklater, A.K.J. (2022). Supplemental reflective blankets and wool socks help maintain body temperature in dogs undergoing celiotomy procedures: a prospective randomized controlled clinical trial. J. Am. Vet. Med. Assoc. 260(11): 1316-1323.

Onozawa, E., Azakami, D., Seki, S., Hamamoto, Y. and Ishioka, K. (2021). Effect of an insulation device in preventing hypothermia during magnetic resonance imaging examinations for dogs and cats under general anesthesia. Animals. 11(8): 2378.

Redondo, J.I., Suesta, P., Gil, L., Soler, G., Serra, I. and Soler, C. (2012). Retrospective study of the prevalence of postanaesthetic hypothermia in cats. Vet. Rec. 170(8): 206.

Redondo, J.I., Suesta, P., Serra, I., Soler, C., Soler, G., Gil, L. and Gómez-Villamandos, R.J. (2012). Retrospective study of the prevalence of postanaesthetic hypothermia in dogs. Vet. Rec. 171(15): 374.

Rodriguez-Diaz, J.M., Hayes, G.M., Boesch, J., Martin-Flores, M., Sumner, J.P., Hayashi, K., Ma, E. and Todhunter R.J. (2020). Decreased incidence of perioperative inadvertent hypothermia and faster anesthesia recovery with increased environmental temperature: A nonrandomized controlled study. Vet. Surg. 49(2): 256-264.

Rufiange, M., Leung, V.S., Simpson, K. and Pang, D.S. (2020). Prewarming followed by active warming is superior to passive warming in preventing hypothermia for short procedures in adult rats (Rattus norvegicus) under isoflurane anesthesia. J. Am. Assoc. Lab. Anim. Sci . 59(4): 377–83.

Sakata, H., Walsh, V., Chambers, J.P., Bridges, J. and Sano, H. (2020). Effect of insulation with bubble wrap and an absorbent pad on heat loss in anaesthetised cats. N. Z. Vet. J. 68(6): 324–330.

Sessler, D.I. (2001). Complications and treatment of mild hypothermia. Anesthesiology. 95(2): 531–543.

Sessler D.I. and Schroeder, M. (1993). Heat loss in humans covered with cotton hospital blankets. Anesth. Analg. 77(1):73-7.

Taguchi, A. and Kurz, A. (2005). Thermal management of the patient: Where does The patient lose and/or gain temperature? Curr. Opin. Anaesthesiol. 18(6): 632–639.

Tan, C., Govendir, M., Zaki, S., Miyake, Y., Packiarajah, P. and Malik, R. (2004). Evaluation of four warming procedures to minimise heat loss induced by anaesthesia and surgery in dogs. Aust. Vet. J. 82(1-2): 65–68.

Tortorici, M.A., Kochanek, P.M. and Poloyac, S.M. (2007). Effects of hypothermia on drug disposition, metabolism, and response: A focus of hypothermia-mediated alterations on the cytochrome P450 enzyme system. Crit. Care. Med. 35(9): 2196–2204.

Tunsmeyer, J., Bojarski, I., Nolte I. and Kramer, S. (2009). Intraoperative use of a reflective blanket (Sirius® rescue sheet) for temperature management in dogs less than 10 kg. J. Small Anim. Pract. 50: 350-355.

Vitez, T.S., White, P.F. and Eger, E.I. (1974). Effects of hypothermia on halothane MAC and isoflurane MAC in the rat. Anesthesiology. 41: 80-1.

Zhang, E.Q., Knight, C.G. and Pang, D.S. (2017). Heating pad performance and efficacy of 2 durations of warming after isoflurane anesthesia of Sprague-Dawley rats (Rattus norvegicus). J. Am. Assoc. Lab. Anim. Sci. 56(6): 786-79.